

Programming Ubiquitous Things
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Infrared and Ultrasonic Location Systems

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Infrared and Ultrasonic Location Systems

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What are infrared and ultrasonic location systems good for ?

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Introduction (1/2)

- **Light and sound**:
  - they move freely in open space
  - are both largely **blocked by the materials** such as walls, curtains, and partitions that humans use to define the borders of their living spaces
- These two types of signals are **well suited for indoor location systems**:
  - they can determine **which room a user is** in with high accuracy
- High relevance of room-level location information for many **context-aware applications and services**:
  - while an application like navigation requires absolute locations
  - many others rely instead on the semantics associated with a room name or room type
  - a location system with a median accuracy of 0.5 m may seem more desirable than a system which is only able to determine which room a user is in
  - however, you may rethink this assessment once you consider that the former system may incorrectly infer that the user is in the adjoining kitchen 25% of the time, when in fact he is in the hallway

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Introduction (2/2)

- Solutions presented:
  - use **infrared or ultrasound beacons and listeners** to determine a location
  - the **beacons may be embedded in the environment**, and the **listeners are mobile and vice-versa**
  - use **radio signals** to coordinate the location estimation
  - rely on the **ultrasound or infrared signals**
  - some provide symbolic room-level accuracy
  - can use **proximity** or **time-of-arrival** or **angle-of-arrival** to determine the user's location within the room with **room-5–10 cm accuracy**

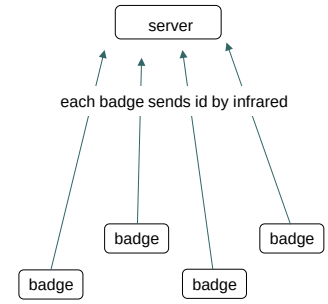
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Room-Level Localization via Proximity - ActiveBadge

- The **first indoor location system** was the **Active Badge**:
  - developed in **1990** at the Olivetti Research Laboratory
- Determines the room in a building where people are located by having **each person wear a small (40-g) badge-like device that sends a unique pulse-width** modulated infrared code every 15 s
- **These codes are received by base stations** mounted on the ceilings of offices, hallways, and meeting rooms
- **Base stations decode the received infrared signals** and forward the decoded **badge-IDs to a centralized location server** using the building's wired networking infrastructure
- Because **base stations are mounted in known locations** and because the **signals rarely propagate beyond a single room**, the **server can infe**r with high probability in which room the badge is beaconing
- Because the infrared **badges take only 0.1 s to transmit their unique code**, collisions between simultaneously beaconing badges are unlikely





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There is fundamental problem with ActiveBadge (infrared signals) which is...

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Room-Level Localization via Proximity - ActiveBadge

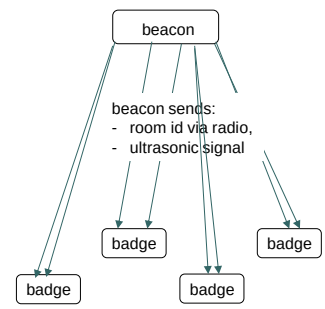
- Infrared signals are **easily blocked by fabric**:
  - the badges need to be worn on the **outside of people's clothing**
- Badges in pockets or belts were often **obscured by tables and desks** when people were seated:
  - "**clipped to a breast pocket**" emerged as the best position in which to wear the Active Badge
- More disadvantages:
  - **requires specialized infrastructure** in the form of base stations to listen for badge IDs
  - **requires users to purchase and carry the badge itself**
- Some nice features:
  - simple design and use of low power parts enable:
    - an Active Badge to **run for more than a year** before requiring the batteries to be changed
  - **simplicity** in design and architecture:
    - commercial infrared badge systems as those sold by Versus have changed little since the Active Badge system was developed

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Room-Level Localization via Proximity – WALRUS (1/2)

- WALRUS uses **PC/PDA speakers and microphones** to **send/receive ultrasonic signals** to convey proximity:
  - it **does not encode the room's ID** using the ultrasonic signal, just **proximity**
  - **it encodes the room's ID using a radio side channel (802.11 datagram),** i.e, **PCs send an 802.11 datagram containing the rooms' identifying** information
  - the **PCs that are serving as beacons** periodically emit a 10-ms pulse of 21-kHz ultrasound
  - as the **ultrasounds and radio datagram are transmitted at the same time**, WALRUS **clients do not need to constantly monitor their microphones**
  - rather, **they can listen for an 802.11 datagram and, only when received, listen for an ultrasound signal**



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Room-Level Localization via Proximity – WALRUS (2/2)

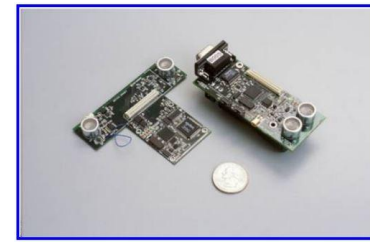
- Given that there is no actual data encoded in the ultrasound:
  - **the client's audio task is reduced to simply looking for sufficient energy** in the 21-kHz band to connote proximity
  - this also extended the useful range of the ultrasound signals generated by the beacons to 13 m in their experiments
- Because **beaconing PCs are not coordinated** in WALRUS:
  - there is the potential for **client devices to receive the radio datagram from one beacon and associate it with the ultrasound from a different beacon**, in effect, incorrectly identifying which room it is in
  - the **experiments show that while this is unlikely** when only a small number of WALRUS beacons are within 802.11 range of each other, by the time **the number of beacons grows to 25**, the **error rate increases to more than 50%**
  - this issue can be addressed by **using a central coordinator to schedule the PC beacons**

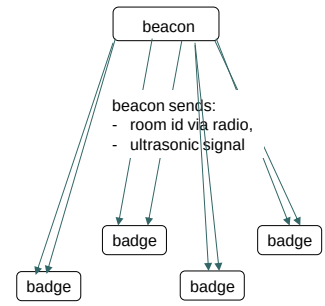
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Cricket - Ultrasonic Time of Flight (1/2)

- The **Cricket** system:
  - developed as part of the MIT Oxygen project
  - sought to enable **sub room-level location using ultrasound**, and
  - to do it in a **privacy preserving, decentralized fashion**
- **Beacons are placed on ceilings** or high on the walls in the environment and **advertise their identity using a combination of RF and ultrasound**:
  - **Cricket beacons encode their identity using RF** and **send ultrasound pulses** containing no digital data (similar to WALRUS)
  - Cricket designers wanted to be able to place multiple Cricket beacons in a single room to allow Cricket listeners to figure out **which part of the room (which seat at the table, which work area, which bed, etc.) the user was occupying**





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Cricket - Ultrasonic Time of Flight (2/2)

- Ultrasound travels very slowly (in room-temperature air, sound travels at only 343 m/sec = 0.343 m/ms)
- On receiving the radio ID from a beacon, **Cricket listeners not only listen for an ultrasound pulse, but time how long it takes to arrive**
- Because the radio signal travels almost instantaneously relative to the ultrasound:
  - **the delay between start of the radio transmission and the observation of the ultrasound pulse is a close approximation of the time of flight of the ultrasound** which can, in turn, be **converted into an estimate of the distance the ultrasound traveled**
- By **estimating and comparing the distances of the beacons being observed**, a Cricket **listener can accurately predict which beacon is the closest**
- Thus, Cricket can be used as:
  - a **room-level location system**, when **beacons are sparsely deployed**, and
  - a **sub room location level system**, when **multiple beacons are placed in a room**
- Subsequent extensions to Cricket show that:
  - with **sufficient beacon density**, it can **determine location within several centimeters** and **orientation to within 5°**

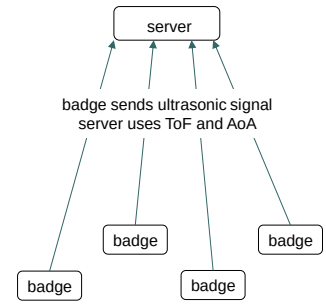
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Absolute Location with ToF and AoA – Active Bat (1/4)

- Goal:
  - to estimate with **high accuracy** the absolute location of a device **within a room**
  - e.g., 110 cm south, 50 cm east, and 35 cm up from the northwest corner of Conference Room 206
- The Active Bat system:
  - was developed by AT&T Research in 1999 uses **ultrasound receivers** to localize small (35 g) pager-like devices called Bats in three-dimensional space
  - it uses **Time of Flight (ToF) and Angle of Arrival (AoA)**
  - it is extremely accurate, estimating location correctly
  - within 5 cm, 50% of the time - within 9 cm, 95% of the time
- Like Cricket:
  - **Bats are located by measuring the travel time of an ultrasonic pulse**
- In contrast to Cricket:
  - **Bats emit the ultrasonic pulses**
  - **receivers in the infrastructure listen** for and time the pulse's travel



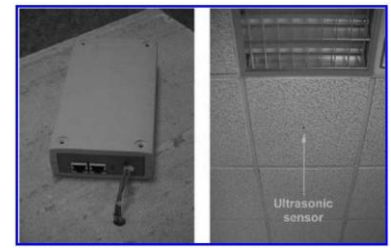


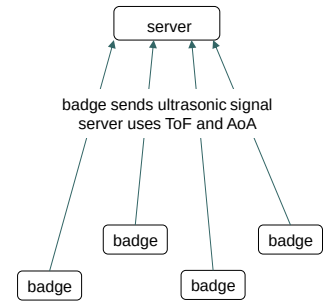
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Absolute Location with ToF and AoA – Active Bat (2/4)

- **Accuracy of the Active Bat** system derives from:
  - its **dense deployment of ultrasound receiver units**
- In the original AT&T deployment:
  - 100 ceiling-mounted receivers were used in a 100-m2 office
  - this density makes it likely that **a Bat's pulse would be heard by at least three** and likely many more receivers
- To estimate location:
  - **receivers pool their time-of-flight observations to a central server** that performs multi-lateration (a generalization of trilateration)
  - location is estimated from three or more ranging estimates from known locations
- Similar to Cricket:
  - reflections of ultrasound are common, and
  - the Bat system uses the redundancy of the grid of receivers to reject these reflections as outliers



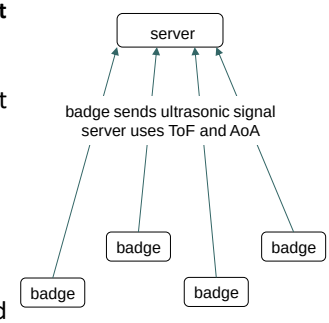


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Absolute Location With ToF and AoA – Active Bat (3/4)

- The Active Bat system is **sufficiently accurate** that:
  - it is possible to place multiple Bats on a rigid object and,
  - by measuring the Bat's location, reconstruct not only the **object's location but also its orientation**
- Experiments in which two Bats were attached to a rigid object 22 cm apart showed:
  - **orientation could be estimated within 10° over 80% of the time**
- The accuracy of the Bat system is dependent:
  - on the **density of ultrasound receivers**
- Active Bat system is **centrally coordinated**; **bats** wishing to be tracked **register their interest** with a central service via radio



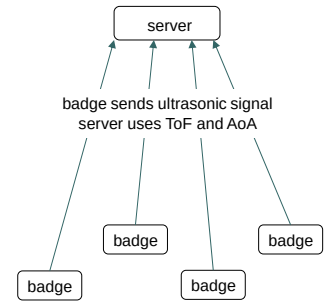
- It employs a slotted schedule to ensure that, at most, one Bat at a time has an ultrasonic pulse in flight
- Ultrasonic reverb can take up to 20 ms to die off in an indoor environment
- Thus, it uses a schedule with 50 slots per second

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Absolute Location With ToF and AoA – Active Bat (4/4)

- At the **start of a slot**:
  - the central server requests (via radio) that the Bat with a given ID send an ultrasound pulse
  - then, the server records the elapsed time and ID of each receiver that reports having heard the pulse
- At the **end of the slot**:
  - the server can compute the distance estimates and,
  - using the receiver's locations, can estimate the Bat's location
- The Bat system:
  - does not need to employ a uniform schedule, and
  - Bats assigned to people can be localized with a higher frequency than those attached to less mobile objects like printers



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comparison

design and performance

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Comparison - design

System	Location Technology	Sender of ID (IR: Infrared US: ultrasound)	Inference avoidance / detection	Location computed by
Active Badge	Infrared	badge ID by IR	Collision detection	Server
WALRUS	Ultrasound+RF	beacon ID by RF	None	Client
Cricket	Ultrasound+RF	beacon ID by RF	Collision detection	Client
Active Bat	Ultrasound+RF	Bat ID by RF	Central schedule	Server

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Comparison - performance



Technology	Infrared proximity (e.g., Active Badge)	Ultrasound proximity (e.g., WALRUS)	Ultrasound TOF (e.g., Active Bat)
Accuracy	★★★☆ Room ID with high accuracy	★★★☆ Room ID with high accuracy	★★★★ 3D location with 5 cm accuracy
Coverage	★★☆☆ Indoor only in room fit with IR receiver/beacon	★★☆☆ Indoor only in room fit with ultrasonic beacons	★★☆☆ Indoor only in room fit with ultrasonic infrastructure
Infrastructure cost	★★☆☆ Infrared receiver or beacon required for each room	★★☆☆ 1 or more ultrasonic receiver or beacon required for each room	★☆☆☆ Requires dense array of ultrasonic receivers
Per-client cost	★★★☆ Inexpensive IR badge/dongle required	★★★★ Software only solution on device with microphone	★★★☆ Inexpensive ultrasonic badge/dongle required
Privacy	★★★★ If localization is performed on the client. Otherwise ★★☆☆ Opt-out easy by removing badge	★★★★ Localization is performed by mobile client	★★☆☆ Localization is performed by infrastructure. Opt-out easy by removing badge
Well-matched use cases	Asset and personnel tracking, indoor mapping/ navigation/tour guides	Asset and personnel tracking, indoor mapping/ navigation/tour guides	Asset and personnel tracking, tangible UIs, fine-grained info services

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